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Laboratory and field testing of surfactants used to meet new workplace exposure standards for respirable dust in coal mines

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LABORATORY AND FIELD TESTING OF SURFACTANTS USED TO MEET NEW WORKPLACE EXPOSURE STANDARDS FOR RESPIRABLE DUST IN COAL MINES

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ABSTRACT: Respirable coal dust is generated during the mechanised mining process and is one of the main occupational health hazards in coal mines. Due to its fine characteristics, it can affect the performance of mining equipment and cause adverse health effects in mine workers. There is a recent focus upon improved dust control measures in Australian mines. This is primarily due to a resurgence in reported cases of coal mine lung dust disease in both NSW and QLD coal mines. New more stringent workplace exposure standards (WES) are currently being introduced for both respirable coal and silica dusts. Considerable research has been carried out in developing coal dust control technologies, and water suppression with added surfactant is one high-level control measure available to coal mines. This paper will review recent dust monitoring results, available control measures and then analyse recent laboratory and field test results for a commercially available surfactant known as DUST KING. These test results will greatly assist mines to consider surfactants as an effective control measure to improve the occupational health of mineworkers.

BACKGROUND AND MOTIVATION

The mechanised mining process used to extract coal in mines generates fine dust particles during the rock breaking process. These dust particles are raised into the workplace and in close proximity to mine workers operating mining equipment causing a health hazard that must be managed to avoid adverse health effects. Prolonged exposure to dust is one of the main occupational health hazards in coal mines. Respirable dust can penetrate into the lungs and can cause a range of dust diseases collectively referred to as coal mine lung dust disease. With the improvement of coal dust controls in coal mines, the prevalence of coal mine lung dust disease has decreased over the last few last decades (Laney and Attfield, 2010). However, new cases are reported in Australia (Cliff et al, 2018), also in China and USA (Blackley et al, 2016, Xu et al, 2017) leading to heightened awareness of the dust hazard in coal mines. In addition to coal dust, a large amount of crystalline silica dust is generated during the mining process, especially for stone cutting (Jokonya, 2014). There were 15 new silicosis cases reported in QLD mining, resources and quarrying industries for the 2019-20 period (Queensland Health, 2020).

Two key factors have led to a resurgence in coal mine lung dust disease in Australia:

1. Improved diagnostic and reporting strategies, and
2. Dust control measures have not kept pace with increased dust make from larger, higher productivity mechanised mining equipment.

To protect miners from adverse health effects, the WES for respirable coal dust has reduced by 40% from 2.5 to 1.5 mg/m^3 TWA-8h and respirable crystalline silica dust by 50% from 0.1 to 0.05 mg/m^3 TWA-8h (SWA, 2019). In NSW, implementation was 1 July 2020 for crystalline silica and is 1 February 2021 for respirable coal dust whilst in QLD, implementation for both dusts was 1 September 2020.

Recent dust monitoring results were presented at the NSW Standing Dust Committee Forum (Coal Services, 2020). Figure 1 shows the number of actual dust exceedances in NSW for both surface and

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underground coal mines in 2019 (in light and dark blue) overlain by the number of exceedances under the proposed WES (in red and grey). It is predicted respirable quartz exceedances will significantly increase by around 3-fold unless new or improved control measures are considered and introduced to address this critical health issue. In QLD, when the new limits are applied to Q1 to Q3-2020 monitoring data for underground coal mines it shows a 5-fold increase in single sample exceedances for respirable coal and near 4-fold for respirable silica (Djukic, 2020). Industry must immediately take action to arrest these predicted dust exceedances.

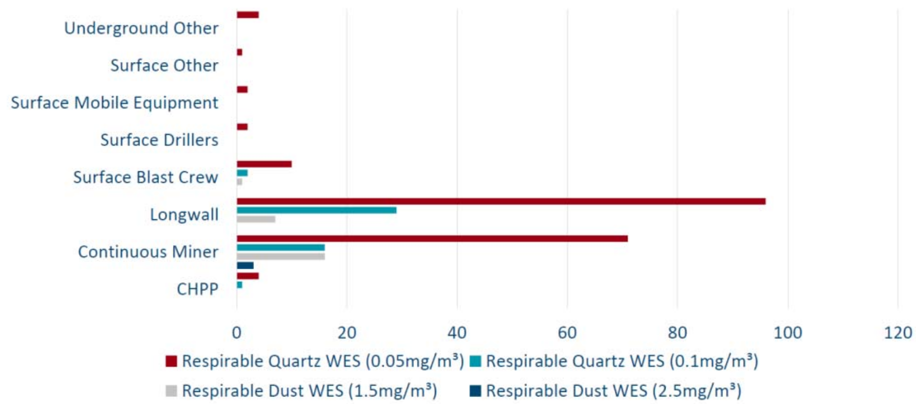

Figure 1: 2019 Comparison WES exceedances (Boyne, 2020)

The hierarchy of controls to manage hazards in the mining industry is widely accepted and is a feature of most guidance material on the topic of dust suppression in mines. Some leading types of engineering controls for dust suppression in underground coal mines are:

- automation involving total removal of workers from dusty environments,
- water infusion to increase the moisture content of in-situ coal,
- high pressure water and atomising sprays to optimise water spray dust capture using very fine water droplets,
- foams used to blanket broken coal and dust, and
- surfactants used to increase the wettability of coal.

Surfactants, an abbreviation for surface acting agents, are a simple and proven cost-effective control measure to reduce water tension thereby improving the wetting capability of water droplets and increasing coal dust capture efficiency (Xu et al, 2017). However, the effectiveness of surfactants warrants further investigation, so mines have a clearer understanding of the underlying science when assessing this control measure for their operations. Other benefits include improved control measure design, optimisation and to screen and develop new surfactants (Meng et al, 2019). Prior studies have shown a wide variance of coal dust suppression improvement using surfactants compared to water only ranging from 0 to 93% (Chandler et al, 1990, Kilau et al, 1996, Kost et al, 1980, Meets and Neethling, 1987 and Tien and Kim, 1997). This study will focus on the use of surfactants in the Australian coal mining context.

LABORATORY TEST PROGRAM

A laboratory test program was scoped and undertaken by WA School of Mines: Minerals, Energy and Chemical Engineering, Curtin University, Kalgoorlie (Chang et al 2020a). The laboratory tests involved three dust types and three surfactants. The dust types were a sub-bituminous thermal coal sourced from Collie WA, a bituminous coking coal sourced from the Bulli Seam South Coast, NSW and a high silica content Hawkesbury Sandstone sourced from a Sydney NSW tunnel project. The three surfactant types were DUST KING, DUST KING A and DUST KING B. DUST KING is a commercially available anionic/non-ionic blend surfactant used for dust suppression in mines, quarries and tunnels (Quarry Mining and Construction Equipment, 2020). Its main use is to improve the dust capture efficiency of water sprays but can also be used on roadways and stockpiles. For water sprays, DUST

KING is simply injected into the existing water system with a pneumatic (sidewinder) pump at a 1:3000 mix ratio (Figure 2). DUST KING A and DUST KING B are variants of the standard DUST KING product selected to test certain constituents of the standard product. The aim was to better understand how the standard product worked and to identify if variants worked better with different dust types.

Figure 2: DUST KING surfactants (left) and dosing pump used for field trials (right).

Static tests, including sink tests and surface tension tests, were firstly conducted to evaluate the effect of doses of each surfactant on the dust suppression efficiency. Wind tunnel tests were then conducted to evaluate the dust suppression efficiencies of the surfactant solutions during dynamic progress with a shorter contact time. The latter test method is considered a more reliable indicator of surfactant performance in the field.

Sample Preparation and Test Methods

All dust samples were prepared following the procedures of ASTM (ASTM, 2013). A jaw crusher was used first to crush raw samples to fine particles. Then the samples were dried in an oven at 35 °C until the weight change less than 0.1% per hour. After that, the samples were sieved to a size range of 0 – 38 μm. Surfactant solutions were prepared in deionized water by using a magnetic bar. For each surfactant, DUST KING, DUST KING A and DUST KING B, five different concentrations of solutions were prepared, includes 0% (pure water), 1:1000, 1:2000, 1:3000, 1:4000, 1:5000.

Sink test is one of the most direct and reliable methods to investigate the effect of different surfactant solutions on the dust wettability (Chen et al, 2019). In this test, 0.5 g dust particles were placed on the surface of 80 ml surfactant solution. Sink time was recorded as the duration of the particles disappear from the surface of the surfactant solution. The test was considered to fail when the sink time was greater than 0.5 hour. All the sink tests were run for three replicates, and the average data was used as the final sink time for each test.

Usually, the surface tension of the surfactant solution is one of the main factors that determine the sink time. Thus, the surface tension for each surfactant solution was also conducted. The surface tension of each surfactant solution was tested by using Analite surface tension meter, model 12141. The surface tension tests were run three times for each solution, and the highest data was used as the surface tension for each solution.

A schematic diagram of the wind tunnel is shown in Figure 3. The dimensions of this wind tunnel are 0.5 m (H) × 0.5 m (W) × 4.50 m (L). The cyclone dust collector acted as an exhaust fan and provided an air velocity of 0.68 m/s in the wind tunnel. The water was sprayed by a nozzle (CPB1322 TEEJETBODY and D12-45HSS DISC&CORE, Spraying Systems Co. Pty. Ltd.) with a flow rate of 4.97 l/min. The dust was injected by the dust generator to wind tunnel first until the dust concentration reached a stable state. After that, the pump was turned on to spray water or surfactant solutions. Dust concentrations were measured by a TSI DustTrack™ II handheld aerosol monitor before and after turning on the pump. The dust suppression efficiency was calculated by the following equation:

$$\eta = \frac{C_{before} - C_{after}}{C_{before}} \times 100\% \tag{1}$$

where C_{before} and C_{after} are the dust concentrations before and after applying the water spray, respectively.

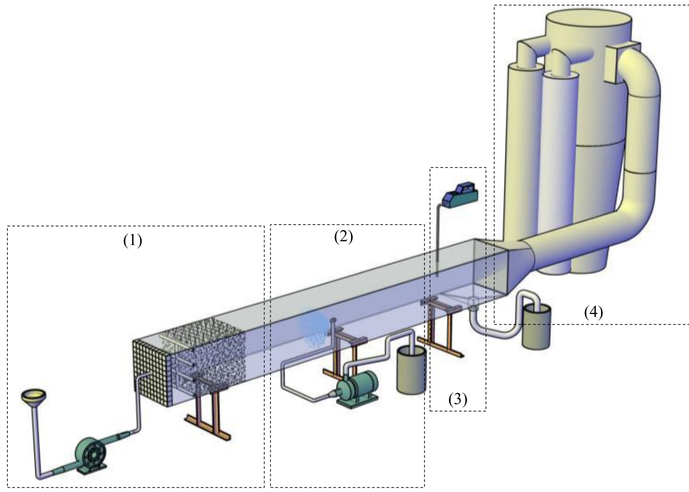

Figure 3: Schematic diagram of the wind tunnel: (1) dust generation part, (2) spray part, (3) dust measurement part, (4) dust collection part (Chang et al, 2020b).

Static Test Results

The surface tensions for three surfactant solutions under different concentrations are shown in Figure 4. As can be seen, the surface tension for pure water is around 65 mN/m. All three surfactants could decrease the surface tension dramatically. The surface tension is dropped from 64.6 mN/m to 45 mN/m by adding 1:5000 DUST KING A, and the surface tension is further reduced to 34.8 mN/m with the surfactant concentration increased to 1:1000. DUST KING B and DUST KING show similar performance in surface tension reduction, both superior to DUST KING A. Sink test results are shown in Figure 5.

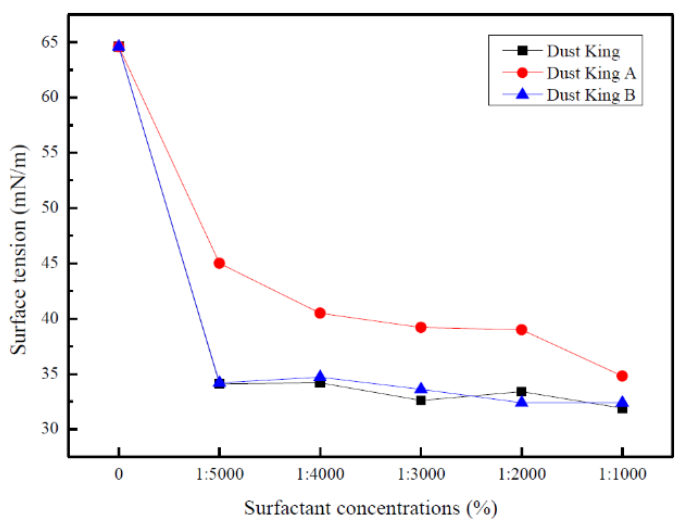

Figure 4: Surface tension of three surfactants with various concentrations

DUST KING A fails to wet both coal types completely in 0.5 hour. For DUST KING, the sink time decreases dramatically with the increase of solution concentration, which drops from around 1500 s with 1:5000 concentration to about 330 s with 1:1000 concentration. DUST KING B gives the best performance amongst three surfactant solutions at all of the five concentrations. However, for the crystalline silica, different trends are observed. All three surfactants wetted the crystalline silica in a short period. Even for pure water, the average sink time is around 150 s. Overall, from the static tests, DUST KING B gives the best performance amongst three tested surfactants.

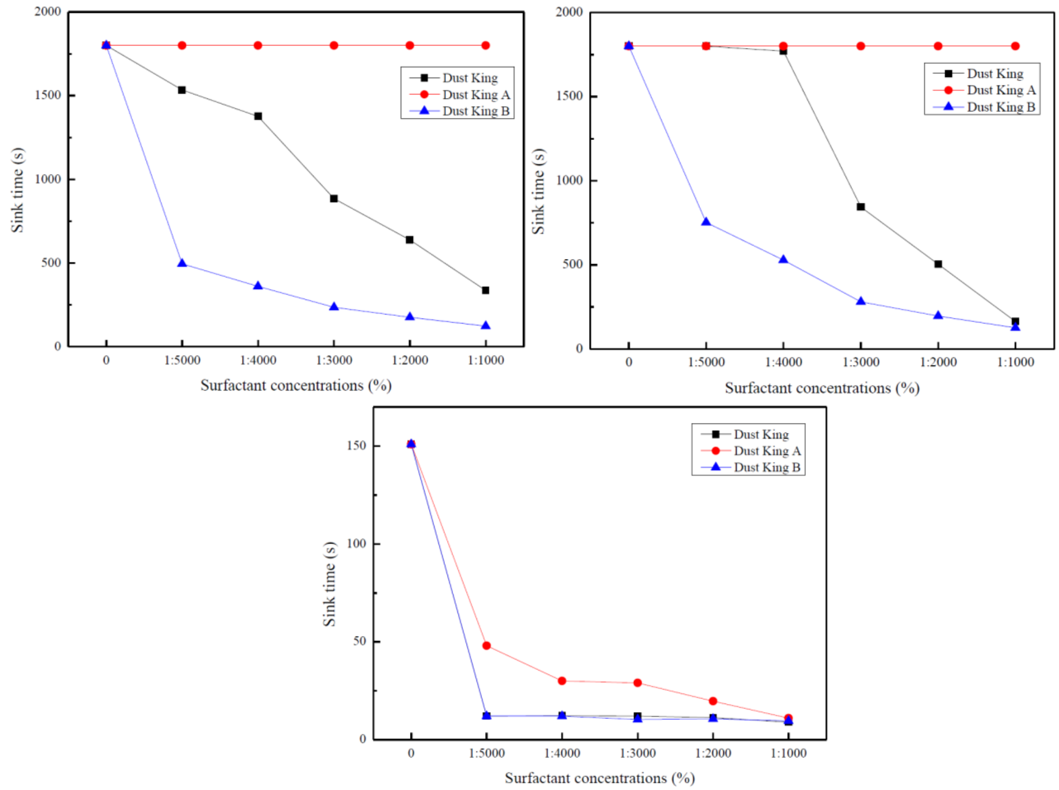

Figure 5: Sink time of Premier thermal coal (top LHS), Bulli coking coal (top RHS) and crystalline silica (bottom) with three surfactants and various concentrations

Dynamic Test Results

The mean dust suppression efficiencies of surfactant solutions for three dust types are presented in Figure 6. As expected, water gives the lowest suppression efficiencies, and DUST KING B gives the highest efficiencies for all three dust types. Consistent with the results of static tests, the surfactant solution with shorter sink time results in a higher suppression efficiency. Suppression efficiency of Bulli coking coal and crystalline silica were similar but greater than Premier thermal coal. The results show different types of coal particles affect suppression efficiency. Overall, the results obtained by wind tunnel tests have a good agreement with the results of static tests. DUST KING B has the best performance in dust suppression.

FIELD TEST PROGRAM

Field tests have been undertaken in NSW South Coast and Hunter Valley underground coal mines to validate the laboratory test data. This involved tests in both development (DEV) and longwall (LW) production panels. Coal type was Bulli Seam coking for South Coast mines and a semi-soft coking for the Hunter Valley mine. All mines were mining thin seams in the order of 2.0m thickness and routinely cutting stone in the floor, roof or interseam bands. Stone types ranged from sandstone, mudstone or siltstone, all containing high levels of crystalline silica. DUST KING was tested at South Coast mines whilst DUST KING B was tested at the Hunter Valley mine.

For South Coast mines, body worn gravimetric sampling was undertaken in accordance with AS 2985 Workplace atmospheres – Method for sampling and gravimetric determination of respirable dust (2.2 L/min flow rate). Whilst for the Hunter Valley mine, co-located stationary gravimetric samplers and Nanozen 9000 Dust Count real-time aerosol monitors were used with a respirable dust size selection inlet in accordance with ISO 7708:1995 Air quality – particle size fraction definitions for health-related sampling (1.0 L/min flow rate). The field test results are shown in Figures 7 and 10.

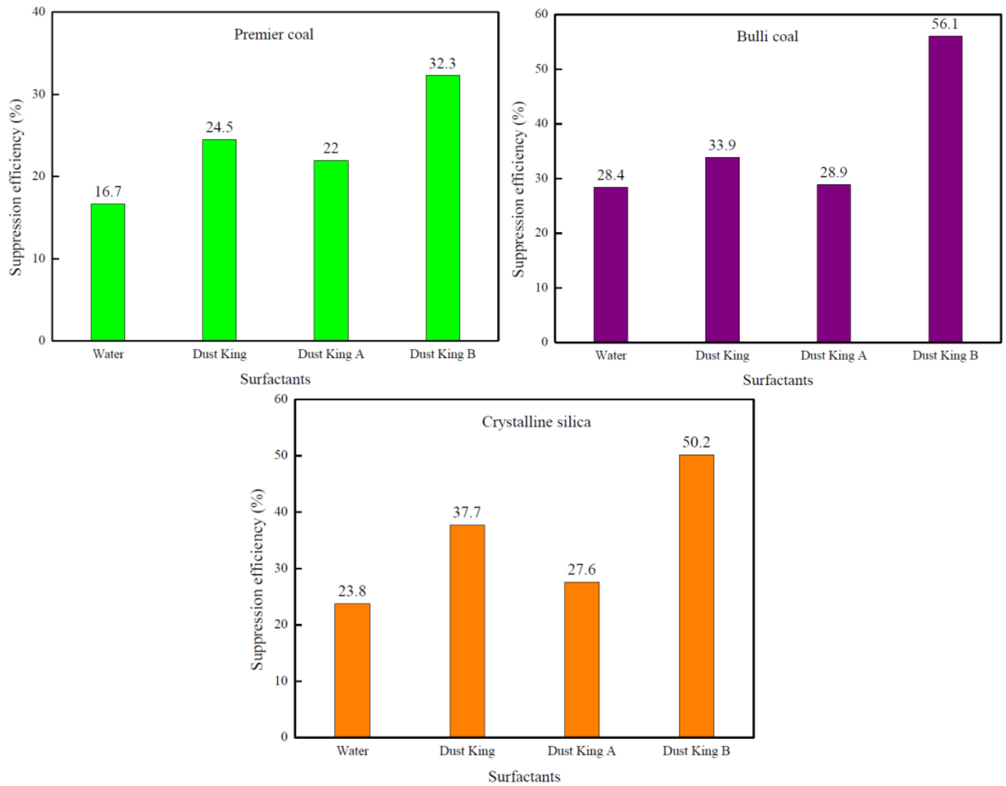

Figure 6: Mean suppression efficiency of Premier thermal coal (top LHS), Bulli coking coal (top RHS) and crystalline silica (bottom) with three surfactants

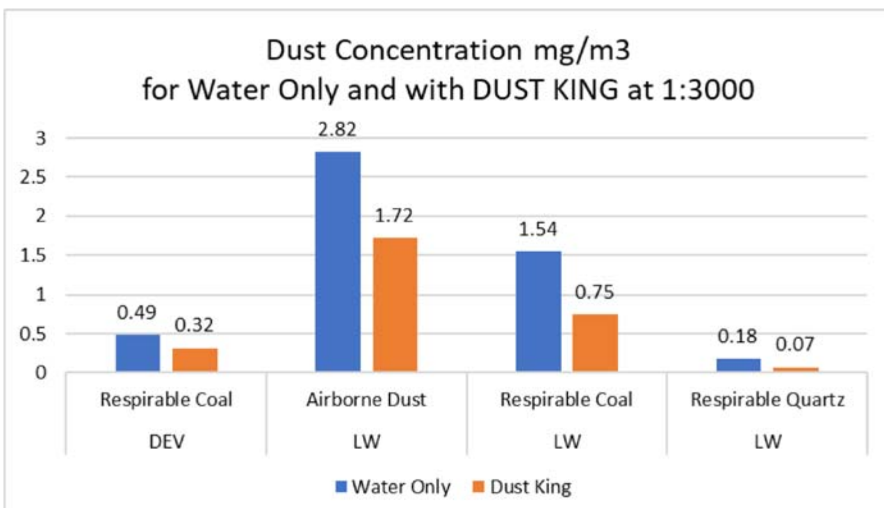

Figure 7: Field test results for DUST KING in DEV and LW panels at South Coast Mines

Field Test Results

DUST KING shows significant reductions in dust readings of between 35 and 51% (mean 43%) for respirable coal dust and 62% for respirable silica dust. DUST KING B also shows significant reductions in dust readings of between 38 and 67% (mean 57%) for respirable dust and 33 to 67% (mean 50%) for respirable silica dust. The accuracy of silica field test data is +/- 0.01 mg/m^3 which makes comparisons between surfactant products difficult to quantify with reasonable certainty at low dust loads. However, the laboratory results undertaken at higher dust loads (above 50mg/m^3) clearly showed DUST KING B was superior for both dust types.

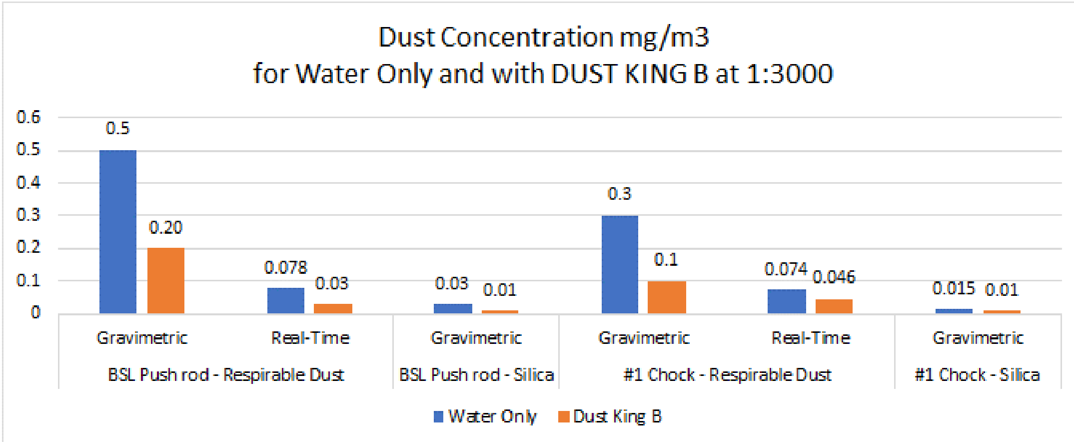

Figure 8: Field test results for DUST KING B in LW panel at Hunter Valley Mine

The real-time data is very useful for the assessment of dust control effectiveness. Due to the scale of the graph the visual impact of the surfactant is less discernible however the large number of 5-second average short interval measurements provides a greater level detail and a better understanding of how the control measure impacts upon dynamic face operations. Furthermore, the real-time monitor had a lower detection limit of +/- 0.001 mg/m^3 and comparisons between water only and surfactant added are more reliable as these are made within shift versus separate days for the body worn gravimetric sampling method.

Box plots show a reduced interquartile range for DUST KING B compared to water. That is, the dust readings are more consistent and the control measure effectiveness is more reliable.

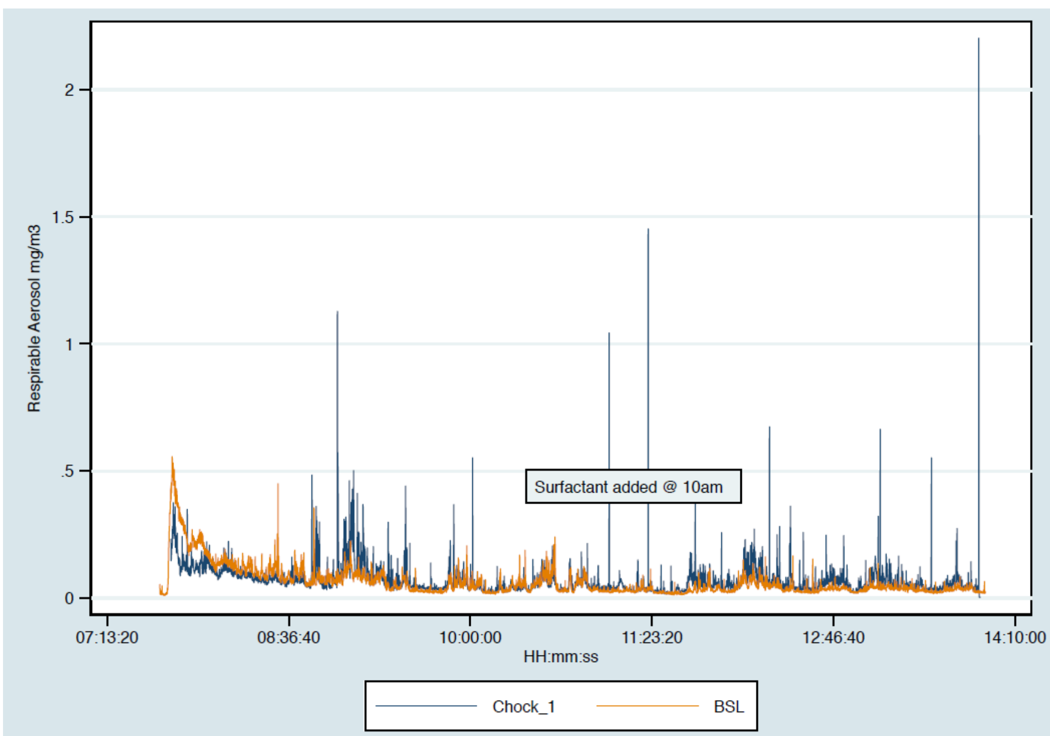

Figure 9: Real time data plot of results for DUST KING B in LW general purpose water for Chock 1 and BSL locations at Hunter Valley Mine

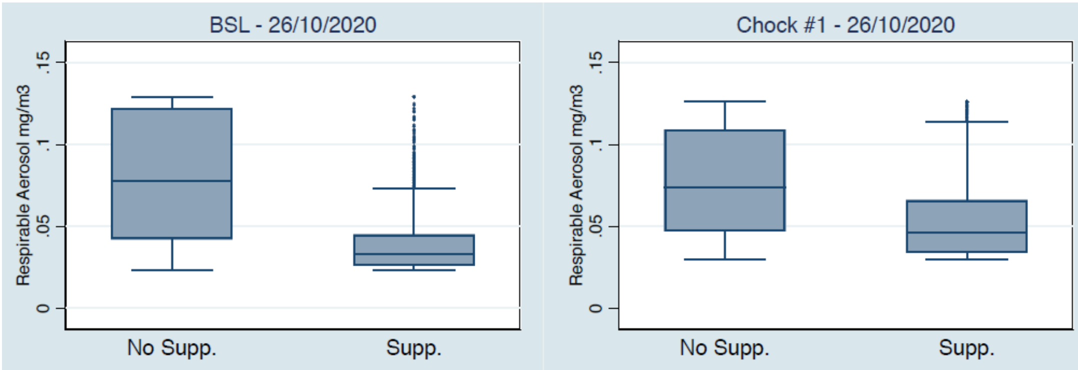

Figure 10: Boxplots of real time data by location for DUST KING B in LW general purpose water by location Hunter Valley Mine

CONCLUSIONS

This study independently evaluated the suppression efficiency of three surfactants in the laboratory and two surfactants in the field with a range of coal mine dusts. Both the static and dynamic laboratory tests showed that DUST KING B gives the best performance amongst three tested surfactants. Field tests validated the laboratory tests, with DUST KING B superior to DUST KING. The reduction in dust concentrations measured using the surfactants in the field trials ranged from 35 to 67% (mean 49%) across all dust types. This reduction is in line with recent WES changes for respirable coal and crystalline silica dusts of 40% and 50% respectively. The study is unique as it uses field tests to validate laboratory tests for a range of surfactants and Australian coal mine dust types, thereby providing operators with confidence in surfactant performance when applied in a dynamic mining environment. The results are also relevant to tunnel, civil and metalliferous mine operators where crystalline silica is the primary dust type and the same WES of 0.05 mg/m^3 also applies to these industries.

ACKNOWLEDGMENTS

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